



Highlights from **TWEPP 2016**

Topological Workshop on Electronics in Particle Physics

Veronica Wallangen

October 14 2016

♦ September 26-30 at Karlsruhe Institute of Technology, Germany

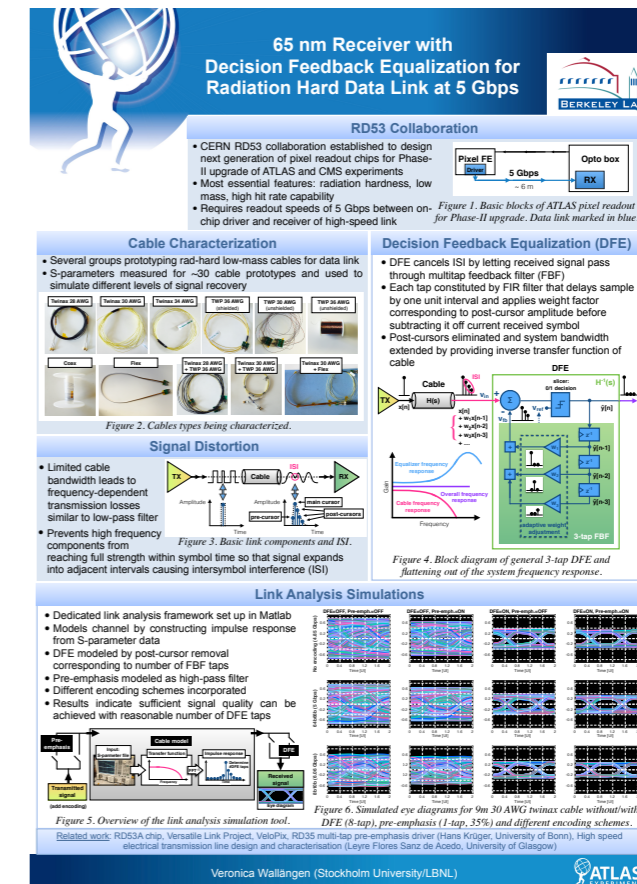
- Webpage: <http://indico.cern.ch/event/489996/>
- Next year: Santa Cruz (UCSC)!

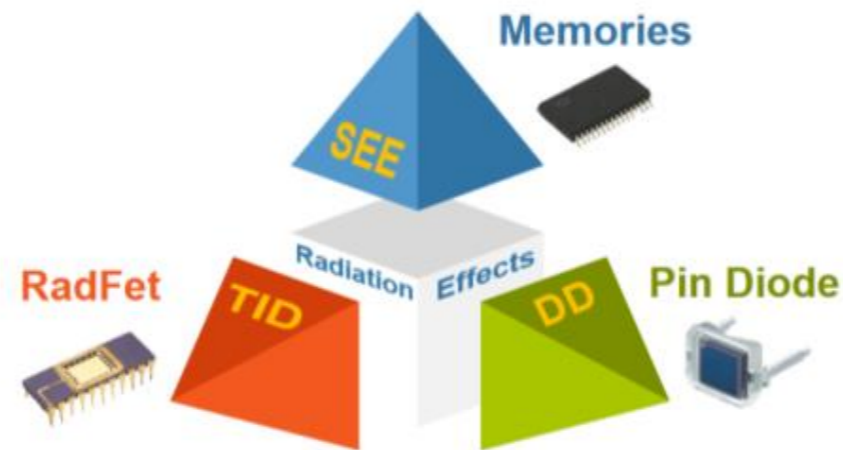
♦ Main focus:

- Experiment upgrades for the HL-LHC
- Radiation hardness in particular

♦ Selected highlights:

- *Radiation Tolerant Issues for the LHC accelerator*
- *The KATRIN (KARlsruhe TRItium Neutrino) Experiment*
- *Invisibility Cloaking for Solar Cells and LEDs*





Radiation Tolerant Issues for the LHC

TWEPP presentation: http://indico.cern.ch/event/489996/contributions/2293861/attachments/1344645/2026756/InviteSpeaker_Salvatore_Danzeca.pdf
Article: https://r2e.web.cern.ch/r2e/Related/12_01_25_POS_RD11-V2.pdf

Radiation Tolerant Issues for the LHC

Radiation Sources



Radiation sources main categories:

- ◆ Direct losses in collimator and absorber like objects
- ◆ Particle debris from beam collisions
- ◆ Interaction of beam with residual gas inside beam pipe

Criticality (how severe effects are we dealing with)

- ◆ 2 x 6.5 TeV (3×10^{14} p each) -> total stored energy of 0.7 GJ, enough to melt 1000 kg Cu
- ◆ Lead to system failures, destroy parts of accelerator

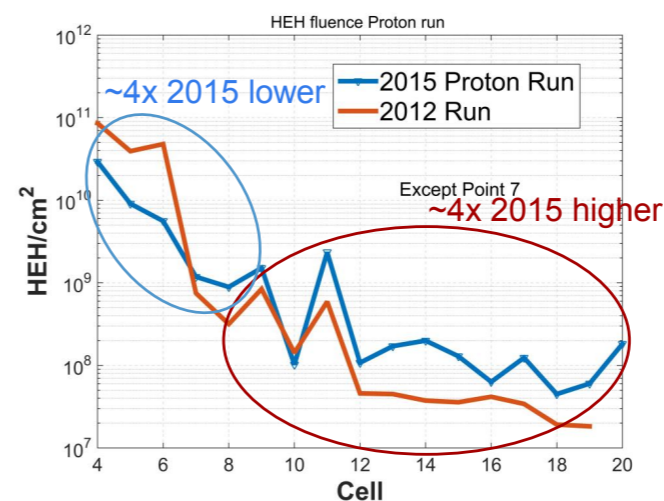
R2E (Radiation-to-Electronics) project

◆ Increased reliability and reduced failure rate:

- Perform radiation tests in a radiation field comparable to the one in the present LHC (variety of source terms results in unique radiation field of mixed particle types and energies)
- Carry out Monte Carlo simulations, monitoring and studies of radiation levels in critical areas
- Create inventory of existing and future electronic systems to be installed in critical areas
- Implement mitigation solutions, such as relocation, added shielding and hardware R&D for radiation tolerant electronics (design and install new equipment)
- Anticipate electronics degradation
- Investigate cause of failures
- Prevent radiation effects rather than mitigate during operation

The radiation levels: a complex matter in the LHC

- In the **2012** the total integrated luminosity was **20fb-1**
- In the **2015** the total integrated luminosity was **4fb-1**
- In the **2015** the bunch spacing changed from 50ns to 25ns



- Analysis based on the **RadMon** measurements up to end November (proton run)
- 2012 vs 2015 highlights the impact of the **25ns** operation
- 2015 HEH fluence higher than 2012 in cells >8 due to the higher **beam-gas interaction**
- **2015 low luminosity** impacts the cell <8 with less fluence
- This was foreseen by the R2E calculations

In the ARC (cell 12>) the increased radiation levels should bring to higher failure rate, **but...**



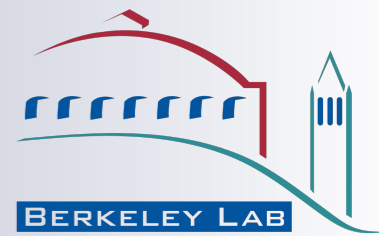
9/28/2016

S. Danzeca - TWEPP 2016

8

Radiation Tolerant Issues for the LHC

Monitoring & Testing



✦ **RadMon system:**

- 379 monitors installed to monitor the radiation to electronics in LHC tunnel and adjacent shielded areas
- Distributed system capable of covering the three axis of the radiation effects
- Monitor radiation levels, anticipate possible device degradation and identify instantaneous failures of electronic equipments
- Validate Monte-Carlo calculations of radiation environment as used to predict present and future radiation levels expected for the LHC

✦ **Beam-Loss Monitoring (BLM) system:**

- Used to cross-check RadMon measurements

✦ **CHARM (Cern High energy AcceleRator Mixed-field) facility**

- A new mixed-field radiation test facility available at CERN since end of 2014
- Multiple (~100) components at once, larger entities for industry applications (satellites, car control systems etc.)

Radiation Tolerant Issues for the LHC

Measuring Radiation Effects

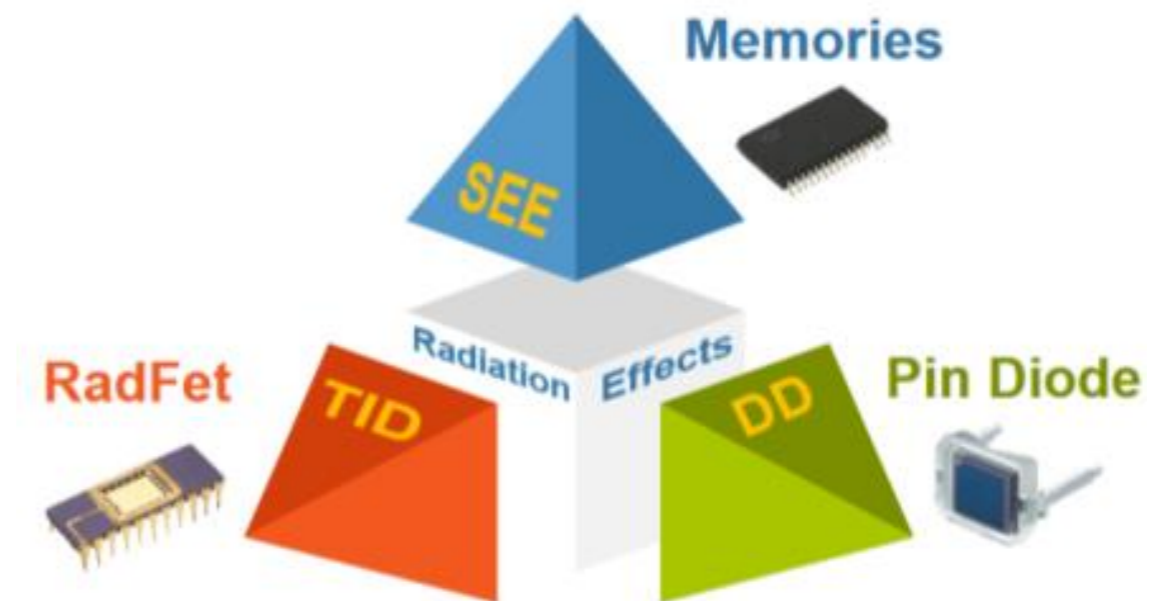
Measurement of three axis of radiation effects:

◆ **Total Ionizing Dose (TID)** in silicon dioxide by using Radiation-sensing Field-Effect Transistors as sensors (RadFETs)

- Charge trapped in silicon will shift transistor threshold voltage
- Drain-to-source current constant \rightarrow threshold voltage function of radiation dose


◆ **Displacement Damage (DD)** in silicon by means of p-i-n diodes

- Particles interacting with silicon lattice will increase threshold voltage
- Monitor shift in threshold voltage (ΔV_f) during injection of current pulse: $\Phi_{eq} \sim \Delta V_f$



◆ **Single Event Effects (SEE)** caused by High Energy Hadrons (HEH) and thermal neutron fluence counted in SRAM memory

- Single Event Upset (SEU): energy deposited by single ionizing particle changes state of memory cell
- Number of SEUs proportional to incoming particle fluence



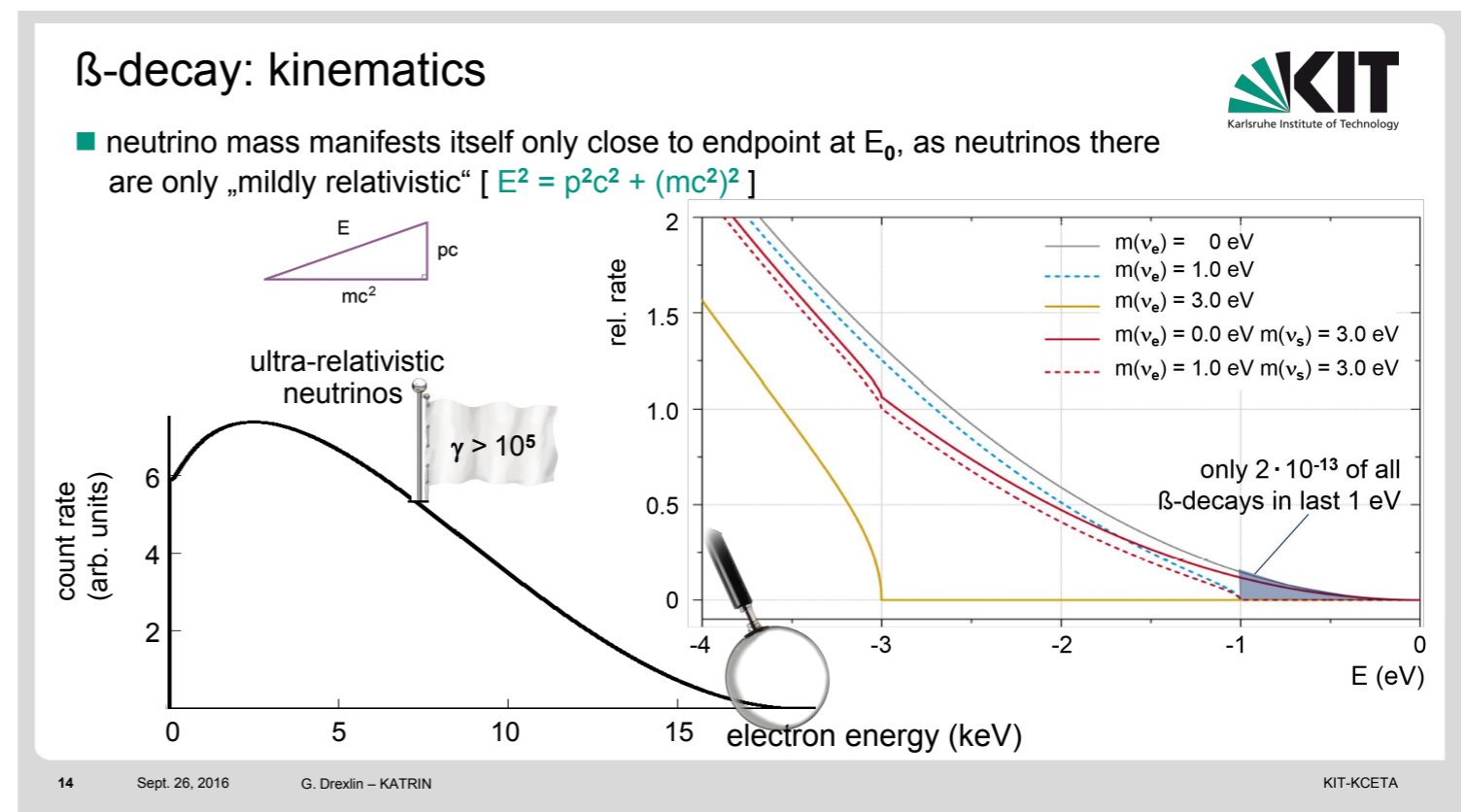
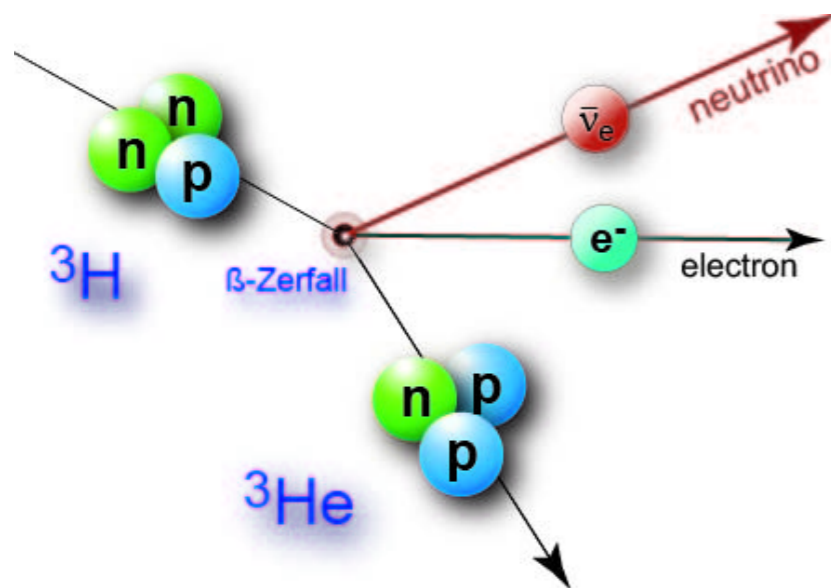
The KATRIN (KARlsruhe TRItium Neutrino) Experiment

TWEPP presentation: [http://indico.cern.ch/event/489996/
contributions/2299592/attachments/1343382/2024041/Drexlin.pdf](http://indico.cern.ch/event/489996/contributions/2299592/attachments/1343382/2024041/Drexlin.pdf)

The KATRIN Experiment

Neutrino Mass Measurements from β Decay

- ♦ **Aim: precise measurement of neutrino mass**
 - order-of-magnitude improvement of current upper mass limit (2.3 eV \rightarrow 200 meV) - or discover actual mass!
- ♦ **Neutrinos massless in Standard Model, going beyond: massive neutrinos**
 - implied by neutrino oscillations: neutrino created with specific lepton flavor can later be measured to have a different flavor (Nobel Prize 2015)
- ♦ **Neutrinos produced in β decay of tritium to helium**
 - electron and anti-neutrino released
 - sharing transition energy in the form of kinetic energy and rest masses
- ♦ **Designed to produce accurate spectrum of number of high-energy electrons emitted**
 \rightarrow low-energy neutrinos
- ♦ **Massive neutrinos must carry away at least the amount of energy equivalent to its mass by $E = mc^2$**
 \rightarrow drop off in electron spectrum



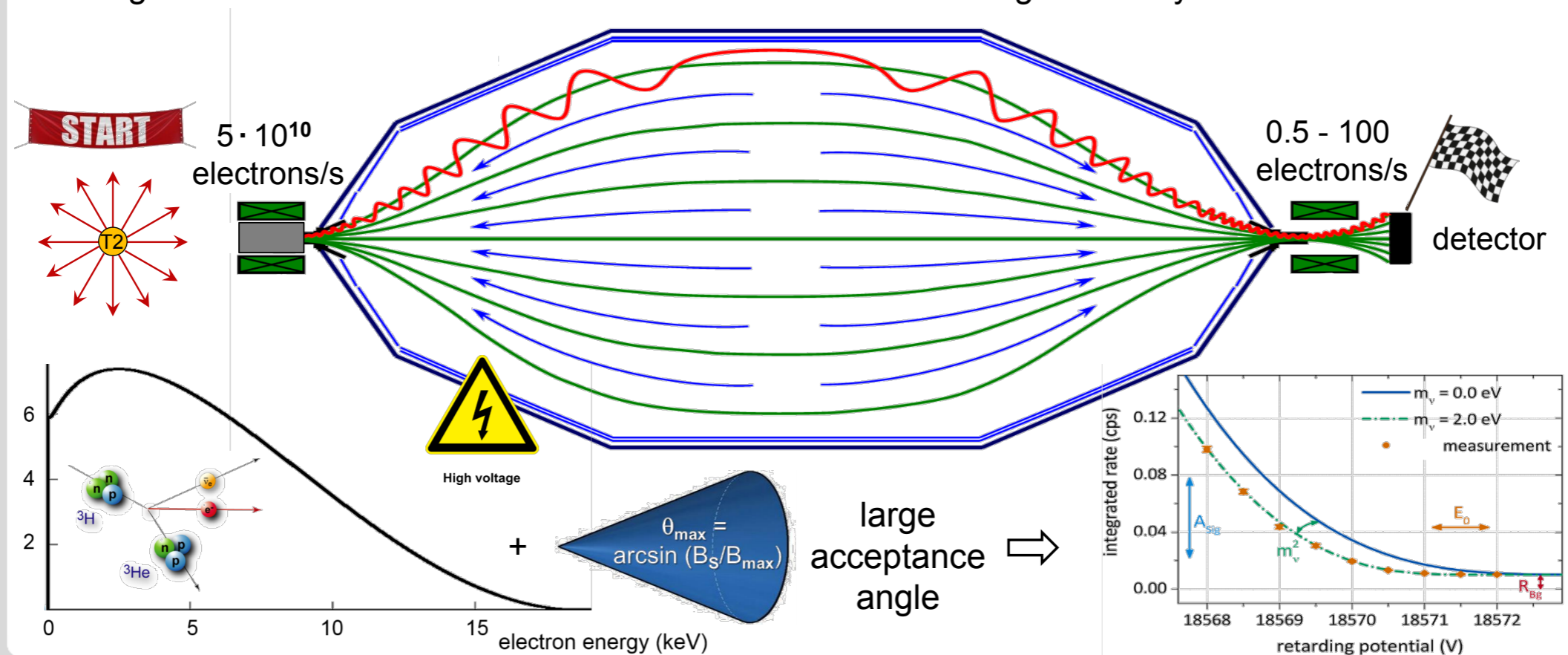
The KATRIN Experiment

The Spectrometer (High-Energy Electron Filter)

- ✦ In most β decay events, electron and neutrino carry roughly equal amounts of energy
- ✦ Events of interest: electron takes almost all the energy and neutrino almost none (occurring \sim once in a trillion decays!)
- ✦ **MAC-E Filter (Magnetic Adiabatic Collimation combined with an Electrostatic Filter)** used to filter out such events

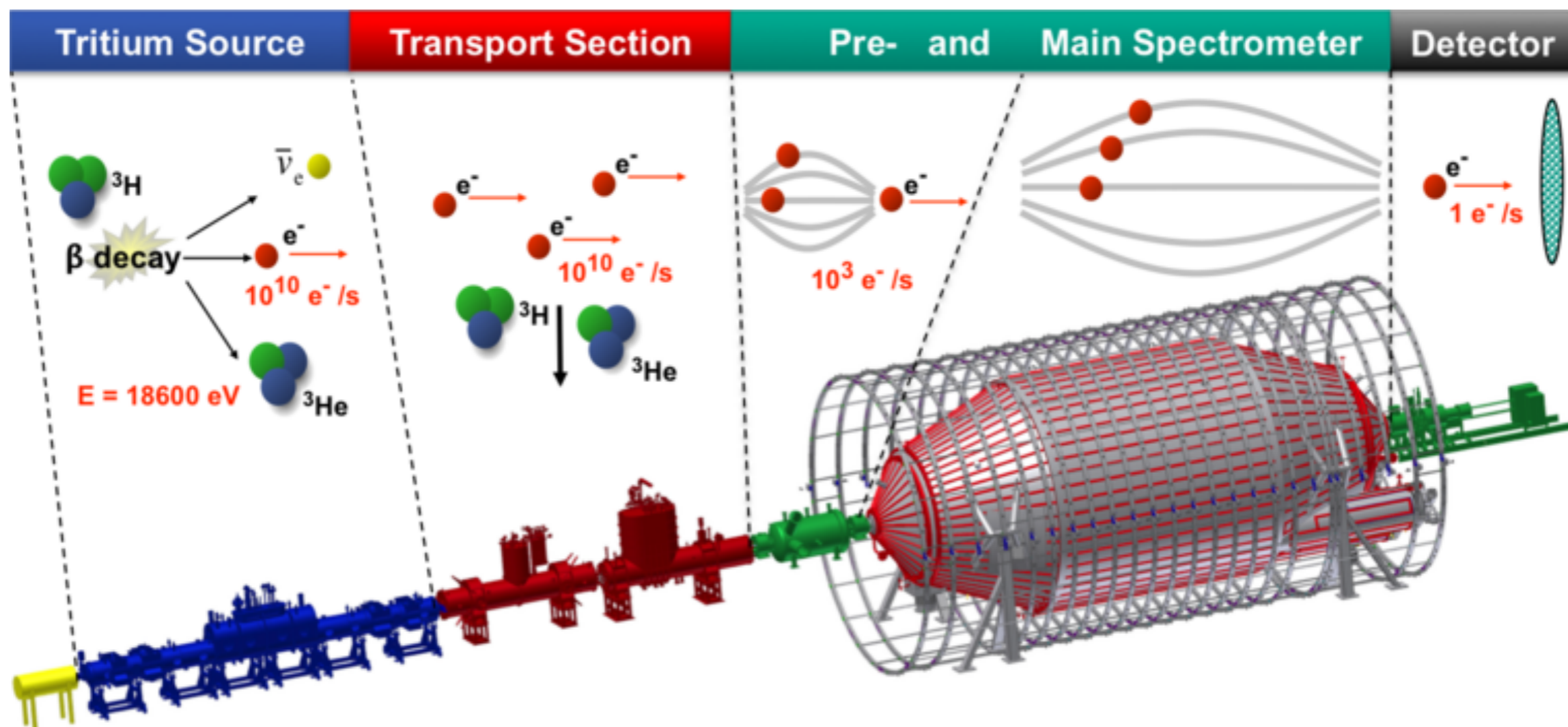
MAC-E principle: high-intensity tritium β -spectroscopy

■ Magnetic Adiabatic Collimation & Electrostatic Filter: scan high-intensity T2 source



The KATRIN Experiment

Operation Overview

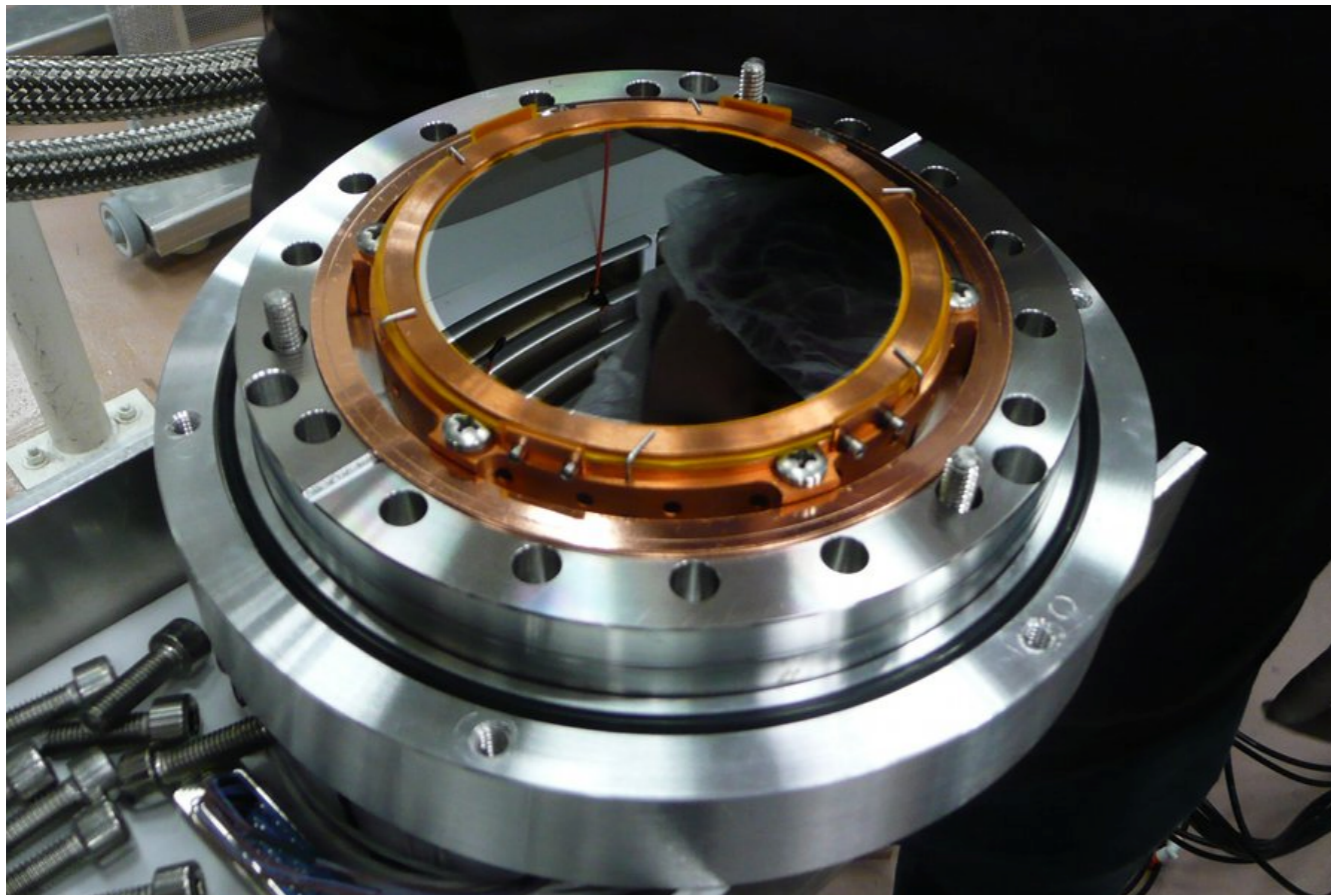


- ✦ Electrons isotropically emitted at tritium source (neutrinos escape undetected)
- ✦ Two superconducting solenoids produce magnetic field to guide electrons into spectrometer
- ✦ Electron beam running against retarding electrostatic potential formed by system of cylindrical electrodes that stops all electrons below certain threshold
- ✦ Low energy electrons rejected by the pre-spectrometer, main spectrometer offers finer energy resolution
- ✦ Electrons with enough kinetic energy to pass electrostatic barrier are reaccelerated and collimated onto a detector where they are counted
- ✦ Count rate varies with spectrometer potential and hence gives integrated β -spectrum

The KATRIN Experiment

Electron Counting Detector

- ✦ **Electron counting done by Focal Plane Detector (FPD):** multi-pixel silicon semiconductor detector
- ✦ **Counting not sufficient...**
- ✦ **Energy, spatial, and temporal information important for understanding of:**
 - operation of apparatus (position-sensitive detector allows varying electric potentials to be mapped and to apply corrections to each detected electron)
 - sources of background (electrons produced by ionization, cosmic ray interactions, gamma rays from natural radioactivity of surrounding materials)



The KATRIN Experiment Outlook (+ fun fact)

- ◆ Main spectrometer 10 m diameter, 23 m long, 200 ton
- ◆ Manufactured in Deggendorf (about 400 km from Karlsruhe)
- ◆ Required 9000 km shipping detour, last 7 km on narrow streets



- ◆ First run in a few days: guide electrons towards target
- ◆ **Outlook:** Final commissioning planned in mid-2017

Invisibility Cloaking



TWEPP presentation: http://indico.cern.ch/event/489996/contributions/2300977/attachments/1343381/2024040/Wegener_Vortrag_KIT_26.9.2016.pdf
Article: https://www.researchgate.net/publication/277596655_Cloaking_of_Metal_Contacts_on_Solar_Cells

Invisibility Cloaking

Transform Space with Metamaterials

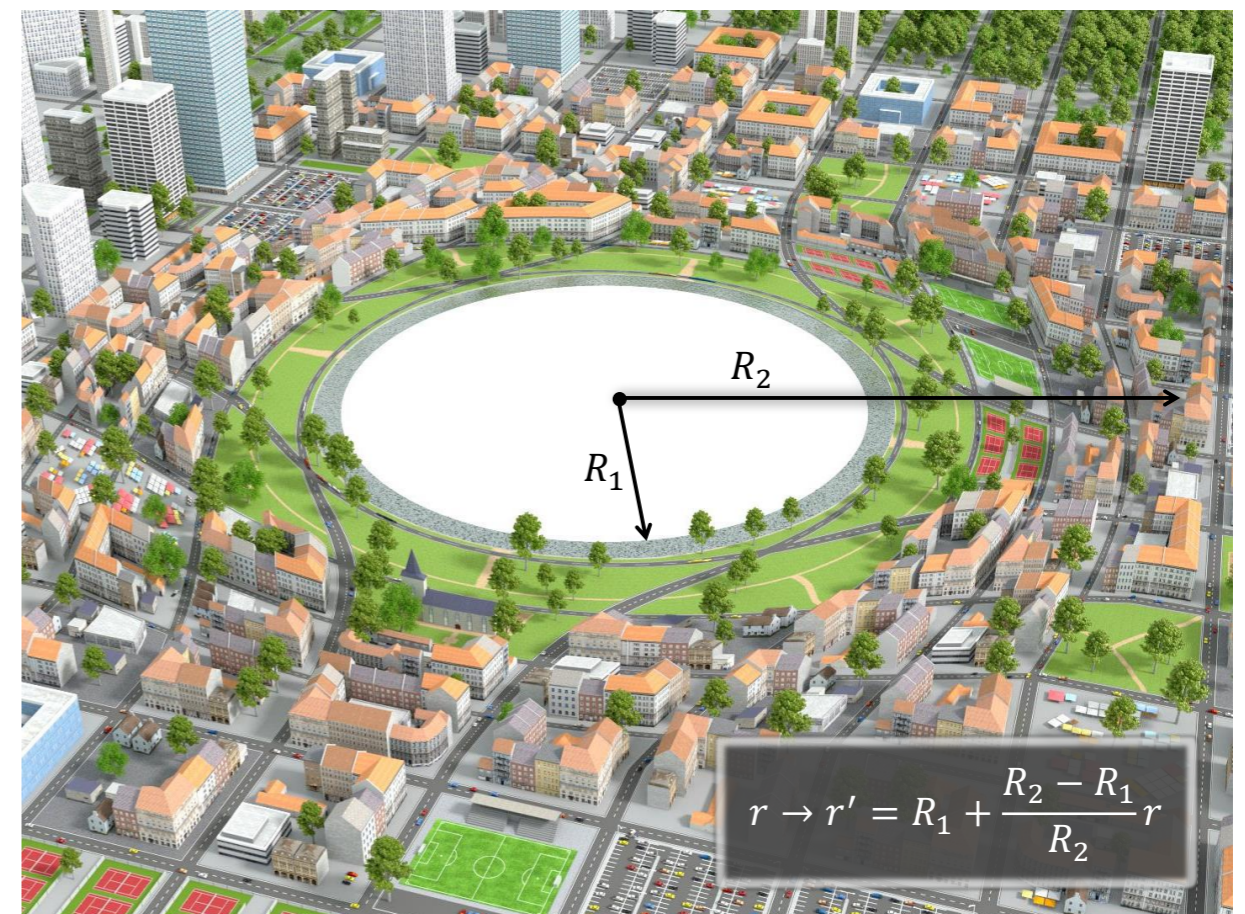
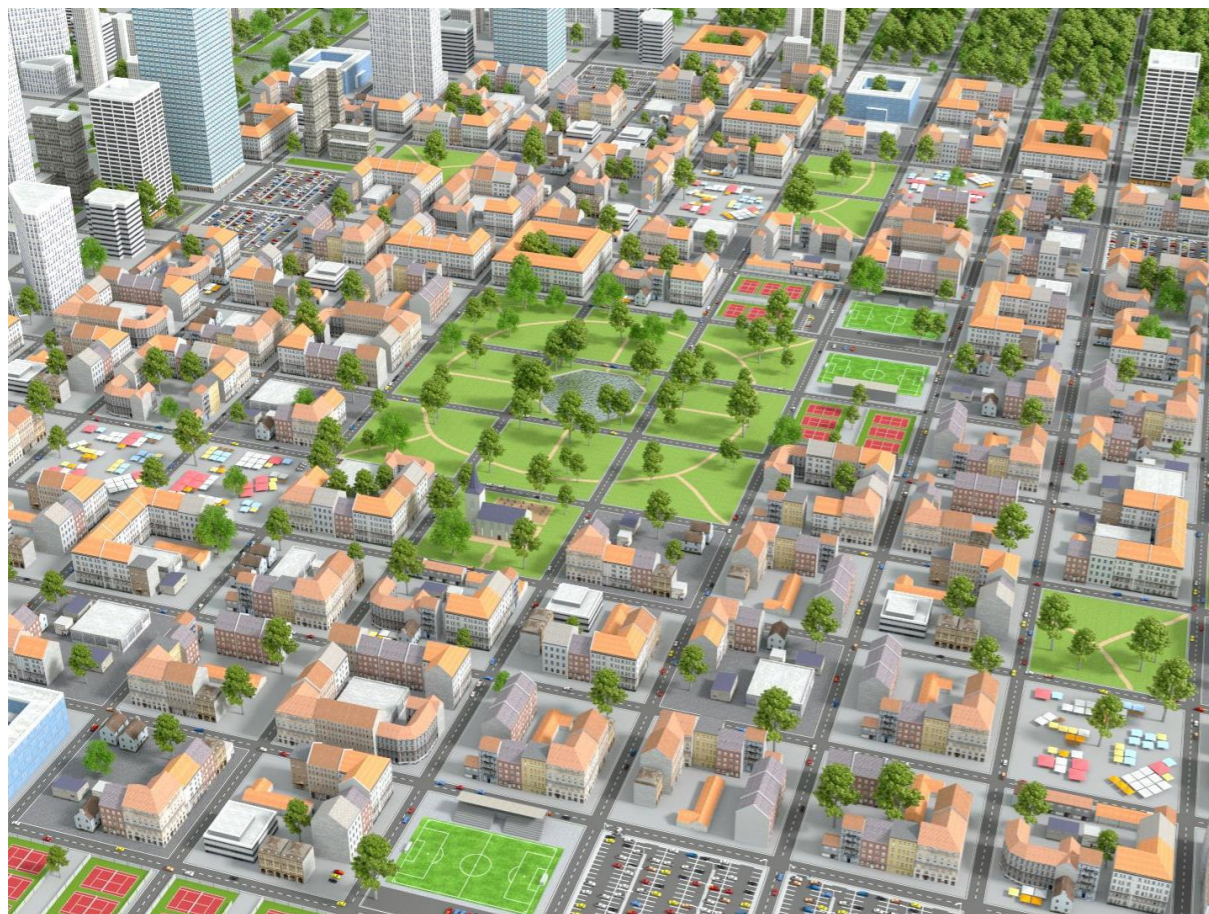
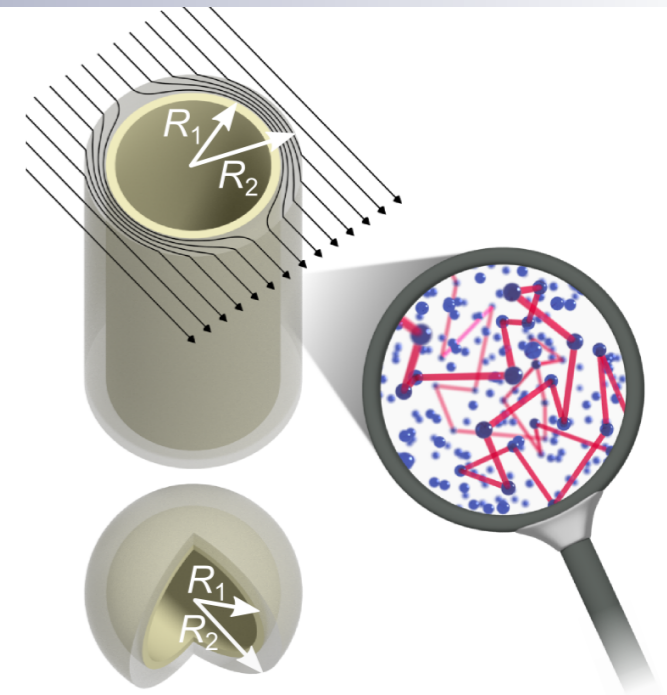
- ♦ Guide incoming light around obstacle using **coordinate transformation**
- ♦ Change refractive index of material: speed and direction in which light travels through material
- ♦ Refractive index distribution calculated through *transformation optics* and cloaking contacts with microstructures designed accordingly
- ♦ **Transformation optics:** mathematical mapping of desired distortions of space onto a distribution of optical material properties in normal Cartesian space
- ♦ Realized through customized inhomogeneous *metamaterials* (material engineered to have properties not found in nature, capable of manipulating electromagnetic waves by their shape, geometry, size, orientation and arrangement)
- ♦ KIT group prominent in this area, specifically developed *first(!)* 3D invisibility-cloaking structures using tailored photonic crystals fabricated with laser writing lithography



<https://www.youtube.com/watch?v=Cw6j-upQfnY>

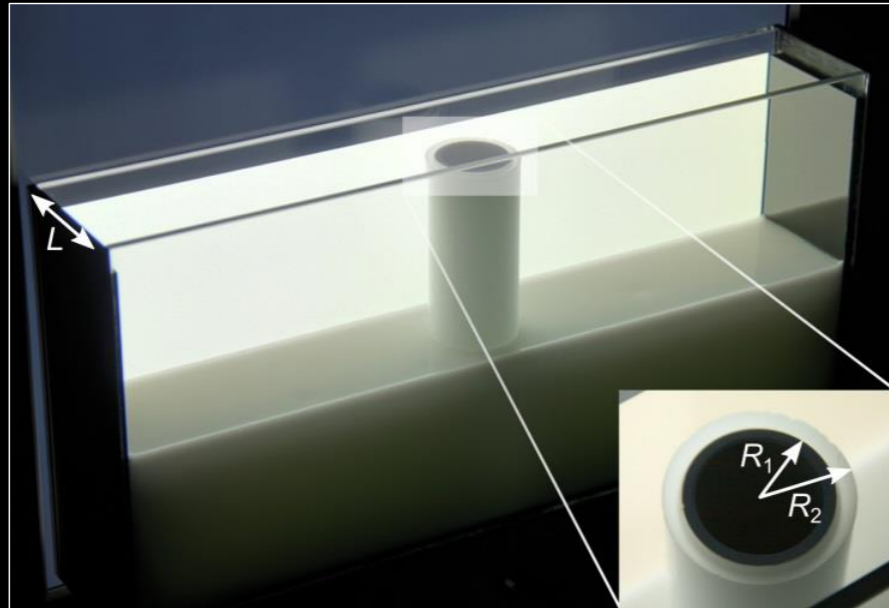
Invisibility Cloaking Principle

- ◆ Essence of transformation for invisibility cloak design: expand scattering free element (point or line) in virtual space to closed volume in physical space
- ◆ EM wave propagating in virtual space corresponds to transformed EM wave in physical space
- ◆ Outside boundary: identity transformation makes EM wave identical to that in virtual space
- ◆ Closed volume does not have corresponding volume in virtual space: objects can be put inside it without causing any disturbance for the EM wave outside -> become invisible to external observers



Invisibility Cloaking Experiments

Experimental Setup



$L = 6.0 \text{ cm}$, $2R_1 = 3.2 \text{ cm}$, $2R_2 = 4.0 \text{ cm}$

Samples



$L = 15 \text{ cm}$, $L = 8 \text{ cm}$, $L = 3 \text{ cm}$, $R = 0.8 \text{ cm}$, $R = 1.2 \text{ cm}$



7.5% diffusive transmittance relative to undoped PDMS cuboid. $D/D_0 = 3.9 = 1.5 \times 2.6$



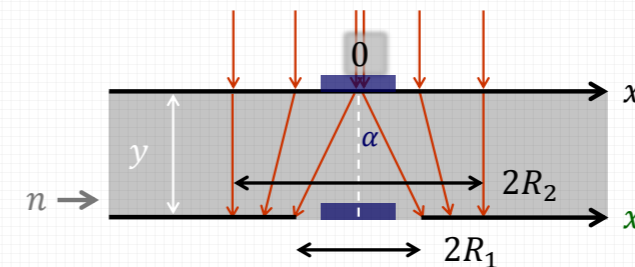
7.5% diffusive transmittance relative to undoped PDMS cuboid. $D/D_0 = 3.9 = 1.5 \times 2.6$

Invisibility Cloaking Applications

- ◆ Cloaking of metal contacts
- ◆ Specifically: increased efficiency (area) of PV panels in solar cells
 - typically convert only 20% of light into electricity
 - at the locations of contact fingers (up to 10% of the surface area) that extract the current generated, light cannot reach the active area of the solar cell

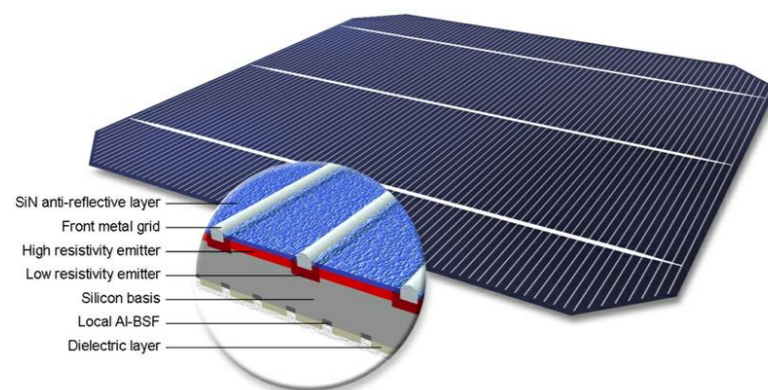
For **normal incidence** of rays, a region of width $2R_1$ can be avoided using the **1D transformation**

$$x \rightarrow x' = R_1 + \frac{R_2 - R_1}{R_2} x; \quad x > 0$$



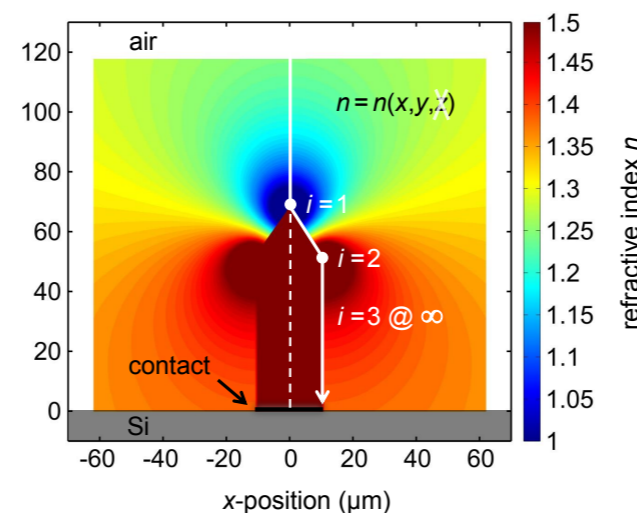
analogous to Pendry's transformation of a point to a circle/sphere; timing is ignored

Invisible Contacts?



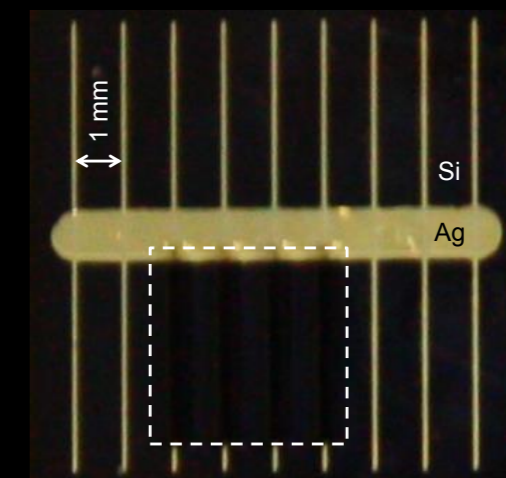
SITEC GmbH, centrotherm website; J.C. Halimeh et al., Opt. Express 21, 9457 (2013)

Invisible Contacts



M. Schumann et al., Optica 2, 850 (2015)

Contacts **are** Invisible



imprinted via master on high-end Si solar cell (FZ Jülich), photograph in cleanroom, 2016

